SIMULATION OF VORTEX INDUCED VIBRATION OF A BLUFF BODY STRUCTURE

SITI NATASHA BINTI MALIK FESAL

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ABSTRACT

Understanding Vortex induced vibration (VIV) phenomenon is essential as it plays important role in designing marine risers which used in oil extraction from the seabed to the offshore platforms were exposed to external flows that may trigger dangerous VIV oscillations. The present two-dimensional numerical simulations of circular bluff body is a continuation of previous efforts trying to study the effect of frequency and amplitudes of the cylinder oscillation that is confined in the cross-flow and inline flow separately. The k-ε turbulence model is used to simulate the turbulent flow to evaluate the drag and lift coefficient of circular towards the flow characteristics which used time independent test (transient) and tested at different Reynolds number between 10000 and 100000 with uniform velocities of 1.35m/s and 13.5m/s. Results from dynamic response of a cylinder bluff body vibrating at frequencies variation of 1.48 Hz, 2.77 Hz and 3 Hz within 0.3m, 0.5m and 0.7m amplitudes variation were observed in this study. It is shown that for inline flow, the vibration at 0.3m amplitude is significantly low for drag and lift coefficient value for Re at 100000 compared to Re at10000. Meanwhile for the cross flow value it is observed that gives high percentages with 39% of drag coefficient and with 59% of lift coefficient compare to inline flow at high amplitude. However at low mode amplitude the cross flow contributes more with 19% of drag coefficient and 11% for lift coefficient compare to inline flow. The result also show that the cylinder oscillate higher at frequency shedding value with higher magnitude for the cross flow compare to the inline flow. Consequently, in order to get better performance, the vortex modes in the wake of oscillating cylinder have been found to be dependent on the amplitude distribution along the length of the model. The results concludes that in order to avoid inevitable vibration it is advisable by increasing damping or splitter when designing marine riser to generate more stable vortex shedding frequency.

ABSTRAK

Memahami getaran Vortex disebabkan (VIV) fenomena adalah penting kerana ia memainkan peranan penting dalam penaik laut yang digunakan dalam pengekstrakan minyak dari dasar laut untuk platform luar pesisir telah terdedah kepada aliran laut yang boleh mencetuskan ayunan VIV yang merbahaya. Simulasi berangka dua dimensi masa ini badan pembohongan bulat adalah kesinambungan daripada usaha sebelum ini cuba untuk mengkaji kesan frekuensi dan amplitud ayunan VIV.Kajian ke atas ayunan silinder pada keadaan menegak dan melintang diuji berasingan. Model gelora k-ε digunakan untuk menilai pekali seretan dan angkat serta ujian terhadap masa dan pada nombor Reynolds yang berbeza diantara 10000 dan 100,000 dengan halaju seragam 1.35m/s dan 13.5m/s. Hasil tindak balas dinamik badan pembohongan menunjukkan silinder bergetar pada perubahan frekuensi dan amplitude pada 1.48 Hz, 2.77 Hz dan 3 Hz dan nilai amplitud adalah 0.3m, 0.5m dan 0.7m. Ia menunjukkan bahawa bagi aliran dalam baris, getaran di 0.3m amplitud adalah lebih rendah untuk pekali seretan dan angkat pada nombor Reynolds 100000 berbanding dengan nombor Reynolds 10000. Bagi nilai aliran menegak memberikan nilai peratusaan sebanyak 39% untuk pekali seretan dan 59% untuk pekali angkat jika dibandingkan pada aliran melintang pada amplitud tinggi. Walaubagaimanapun pada amplitude yang rendah,aliran menegak menyumbang lebih pada pekali seretan sebanyak 19% dan 11% untuk pekali angkat jika dibandingkan pada aliran melintang.Keputusan ini menunjukkan silinder berayun lebih pada frekuensi shedding dengan nilai magnitud yang rendah pada aliran melintang. Kesimpulan mendapati bahawa mod vorteks di tengah-silinder berayun untuk bergantung kepada nilai amplitud di sepanjang model.Untuk mengelakkan getaran musnah,dinasihatkan menambah badan peredam dan badan pembohongan tajam untuk menjana frekuensi yang lebih stabil.

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LIST OF SYMBOL AND ABBREVIATION

VIV	Vortex Induce Vibration
FSI	Fluid Structure Interaction
CFD	Computational Fluid Dynamic
PISO	Pressure Implicit with splitting operators
r.m.s	root mean square
CF	Cross Flow
IL	Inline Flow
1dof	One degree of freedom
St	Strouhal Number
f	Frequency
f_{ex}	Frequency Oscillation
fst	Frequency Shedding
d	Width of shedding body
U	Fluid velocity
Re	Reynolds Number
Ur	Velocity Reduction
Ay	Vibration Amplitude
μ	Free stream velocity
D	Diameter of the bluff-body
v	Kinematic viscosity of the fluid
P	Density of the fluid
C_l	Lift coefficient
C_d	Drag coefficient
F	Amount of pressure
A	Area

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Vortex-induced vibrations of bluff bodies have been studied for a long time due to their importance in both academic researches and engineering applications. The prediction of offshore structures subjected to VIV is one of the most challenging tasks since VIV is a subset of the broader field, the complicated fluid-structure interaction (FSI) phenomenon is involved. For the purpose of understanding this issue, numerous experimental and numerical simulation studies have been carried out on this fluid-structure problem, often dealing with only one degree of freedom (1dof) due to the difficulties and complexities associated mainly with VIV covering from rigid cylinders studies to elastic structured cylinder. For instance, Zhang et.al. (2009) confirms that VIV caused by vortex shedding from the cylinder is a typical fluid-interaction problems.

Generally there are two types of motion involved in order to perform the simulation either free induced motion or force induced motion. The phenomenon of vortex shedding lock-in due to either forced or self-induced cylinder oscillations in crossflow has been extensively studied over the past decades (Konstantinidis et.al., 2003). According to Zhou et.al (1998), different experimental approach to investigate FSI depending on the studies set out to be obtain. For example if the effects of structural vibrations on the wake behavior are of interest only, the approached adopted is to force the structure to vibrate usually in one direction at prescribe amplitude and frequency.

According to Tang et.al (2013), several researcher pointing out experimental works focused on high Reynolds numbers such as Feng (1968), Brika and Laneville (1993) and Khalak and Williamson (1999) was among the first researchers to investigate the VIV problem. Mittal and Kumar (1999), Shiels et al (2001) and Plazeck et al (2009) among the namely few researchers carried out numerical simulations of an elastically mounted circular cylinder subjected to VIV.

Observation by Pattel (2010) shows that flow is very sensitive to the changes of Reynolds number, a dimensionless parameter representing the ratio of inertia force to viscous force in a flow. The periodic flow force, generated by the periodic vortex shedding, affect the cylinder vibration as well as the fluid flow around cylinder, the fluid force and the vortex patterns ,thus forming the complex fluid-structure interaction. Zhang et.al (2009) confirmed that flow induced vibration of an elastic circular cylinder is a nonlinear case.

The VIV of cylinders bluff body influences the dynamics vibrations of offshore riser tubes bringing oil from the seabed to the surface.as well as others, submarine towed array cables and ship moorings in water as well as atmospheric problems including smokestacks, cellular towers and buildings.

According to Michael (1994) the most essential VIV parameters are the lift coefficient, the shedding frequency (Strouhal number), the correlation length, and the shedding frequency bandwidth and are to be obtained from experimental model test.

Similarly, lock-on can also be observed when the cylinder is stationary and the incident mean flow has a periodic component superimposed upon it (Barbi et al., 1986; Armstrong et al., 1986; Hall and Griffin, 1993). This type of flow, termed perturbed flow here, is equivalent to in-line oscillations of the cylinder in a steady incident flow when the perturbation wavelength is large compared to the cylinder diameter (Griffin and Hall, 1991)

There are several others of important parameters in determining VIV response due to vortices. They are reduced velocity, the dimensionless amplitude is the main parameter in performing experiment regarding vortex induce vibration. Reduce velocity is a length of the path per cycle / diameter of the cylinder or can be written as U/f_{ex} D where U is a flow velocity, f_{ex} is the frequency of oscillation of a vibrating body and D is cylinder diameter (characteristic width). The Norwegian

Marine Research Institute (MARINTEK) concluded that among the drag effects of VIV on marine risers are reducing fatigue life time, increase axial tension, increase extreme loads and increase drag resistance.

Previous research had been conducted extensively to study the interaction between vortices and structures. According to Song et al. (2011), majority of the research is focused on rigid cylinders interaction instead of flexible structures. There are few numerical simulation performed in finding VIV response with flexible structures such as Bai et al. (2005).

The computational method is used to analyse a bluff body responses when exposed into specific fluid flow condition. A model is developed using Fluent 15, an application tools for fluid dynamics analysis from ANSYS Inc, whilst the principle data and flow condition is taken from numerical simulation. Both results will be compared to find dissimilarities as many discrepancies occur between measurements and predictions from empirically based codes and CFD is always reported (Song et al., 2011).

1.2 Problem Statement

Unsteady oscillatory phenomenon, which causes the pressure distribution around the cylinders to fluctuate, resulting in forces perpendicular to the flow and bluff body structure. These forces excite forced oscillations of the cylinder known as vortex-induced vibrations. When the frequency of VIV approaches one of the natural frequencies of the structure, the amplitude of vibration is enhanced through a resonant phenomenon known as lock-in or synchronization of the wake. Lock-in and oscillation frequencies can also take place when a cylinder oscillates in line with the incident flow (Griffin and Ramberg, 1976; Ongoren and Rockwell, 1988)

Although the phenomenon of VIV of bluff bodies has been studied extensively, the vast majority of previous studies have concentrated solely on transverse vibrations since the fluctuating lift is the dominant force (Konstantinidis et.al. 2003).Various response curves have been measured showing the amplitude, frequency, and phase of cylinders undergoing VIV. However, since the fluctuating forces responsible for these oscillations have unsteadiness in both lift and drag, the role of stream wise vibrations cannot be ignored. To understand the relationship between frequencies, amplitude, the motion of the cylinder as well as vortex shedding flow, studies on the flow past a circular cylinder undergoing forced vibration should be carried out.

1.3 Objective of Study

The objectives of this research are:

To investigate the effect of the frequency, amplitude, subjected to cross-line and in-line motion of the bluff body on the flow velocity and pressure in the time response (unsteady state).

1.4 Research Scope

The scopes can be listed as:

i. Develop the Computational Fluid Dynamics (CFD) model for the flow simulation of a bluff body.
ii. Cross-sectional area of the bluff bodies $0.0079 m^2$ for circular
iii. Shape is allow to move in in-line flow (X-direction) and cross-flow (Y-direction)
iv. Test at frequency variation motion of the shape ranging from 1.39 Hz, 2.77 Hz and 3.0 Hz.
v. Test at amplitude variation motion of the shape ranging from 0.3m, 0.5m and 0.7m.
vi. Test at Reynolds number variation ranging between 10000 and 100000.

1.5 Significant of Study

The effect of circular cylinder oscillation in lateral (cross flow) and transverse motion (inline flow) towards the flow profiles will be investigated using a simulation. Addressing from low to high Reynolds numbers within the forcing frequency of the structure will be varied accordingly at various values of amplitude in order to analyze the difference. It is believed that such simulations are important for understanding vortex induced vibrations, characterized by controlled oscillations. The knowledge gained from this study later may contribute significantly to the understanding of the VIV and for testing and validation of numerical simulations of the flow around stationary and vibrating bluff bodies which are of great importance in engineering structures especially cylindrical structures, such as subsea pipelines and marine risers.

CHAPTER 2

LITERATURE REVIEW

This chapter introduces the background theories of CFD and the techniques for solving fluid flow problems. Understanding CFD is important in investigating the influences and impacts of fluid flow. The chapter consists of two main sections, by outlines the governing mathematical equations for solving the turbulence models of the flow around bluff bodies and roles of CFD in the study of fluid flow. In first section, which is the major part of this chapter describes the basic concept of vortex shedding and vortex induced vibrations are explained and previous research is examined to illustrate the relevant parameters associated with vortex-induced vibrations. Past simplifications in analysing vortex-induced vibrations are shown and the relevant non-dimensional parameters for properly modelling and scaling the forces associated with vortex induced vibrations are defined. The emphasis is given to the last section of this chapter where the problem of mode ratio variation is introduced with an explanation of the work performed by Dahl (2008). Characteristics of bluff-body flows and important parameter that control such flows, the Reynolds number, the Strouhal number, drag coefficient and lift coefficient, also were discussed.

2.1 VIV phenomenon

Most of the interest in the flow around a cylindrical body oscillating transversely to a free stream is due to its relevance to vortex-induced vibration (VIV). The literature review shows that there is a collective opinion among experts regarding the VIV phenomenon that arises when a body is placed in a flow and the fluctuating lift force due the asymmetric formation of vortices in the wake causes the body to vibrate. The primary reason for the formation of these vortices is the frictional shear stress arising within the boundary layer, which denotes a very thin layer in the neighborhood of the body (Gamino., 2013; Schlichting 1968). This phenomenon of alternating vortex shedding is depicted in a two-dimensional plane as shown in Figure 2.1.

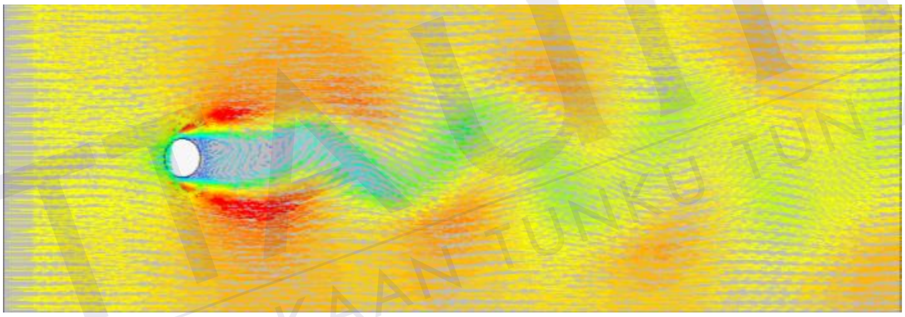


Figure 2.1: Velocity Vector Plot Depicting VIV (Gamino, 2013)

VIV is “a direct consequences of lift and drag oscillations due to the vortex shedding” Wanderley et.al. (2007); Bearman (2000) define for a moving cylinder “the fluid interacts strongly with the cylinder motion and the vortex shedding frequency is captured by the body natural frequency over a wide range of flow speed”. For a fixed or rigid body, the vortex shedding frequency is a function of Reynolds number only. Zhau (2013) investigated that a waves are modelled by oscillatory flow when the hydrodynamics around slender cylindrical structures. He also states that “a highly level of fatigue damage in a relatively short period of time for risers that exposed to harsh ocean environments”. Bai (2005) define “VIV occurs anytime when a sufficiently bluff body is exposed to a fluid flow that produces vortex shedding at, or near, a structural natural frequency of the body”. VIV can occur with high dangerous amplitudes as the continuous periodic vibration of the structure could make it susceptible to fatigue failure.

Computational fluid dynamics (CFD) simulations is presented as another option as an alternative to response models can be applied for VIV assessment to overcome the inherent limitations of the state-of-practice engineering approach (Gamino, 2013).

Generally modelling VIV riser behavior is dependent on a number of empirical parameter such as Strouhal number, correlation length and lift coefficient. Other related flow parameter such as Reynolds number, surface roughness, Keulegan- Carpenter number, and turbulent intensity. Commonly lift coefficient and Strouhal number is the most of the tests provide data for all parameter

2.2 VIV Force Direction

The vortex shedding induces fluctuating forces on the body and, if it is non-rigid, causes it to oscillate in the transverse and in-line direction, thus generating a periodic variation in the force components on the cylinder. The force components can be divided into cross-flow (CF) and in-line (IL) directions, which is important when doing further fatigue analysis. According to Hill (2013), each time a vortex sheds, a force is generated both in the in-line and cross-flow direction, causing an oscillatory multi-mode vibration as shown in Figure 2.2.

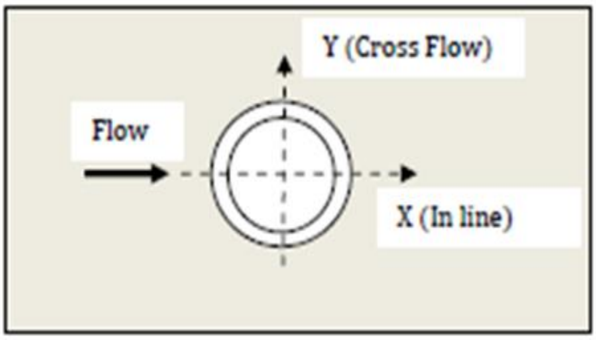


Figure 2.2: Force direction on the model

Consequently, as vortices are being shed on the cylinder surface, the cylinder experiences forces which are periodic in nature. These forces cause the cylinder to continuously vibrate as long as vortices are shed. Chakrabarti, (2005) listed that important hydrodynamic quantities that influence VIV are: Reynolds number, lift coefficient, correlation of force components, shedding frequencies and their interactions, added mass or mass ratio and damping

Dynamic force in CF (transverse) direction to the flow due to vortices reactions is referred to lift force. Transverse cylinder vibration has a large effect on vortex shedding. The correlation of vortex shedding along the cylinder axis increases by transverse cylinder vibration. Increased transverse vibration amplitude (Ay) also increases the ability of the vibration to lock in or synchronize the shedding frequency (Blevins, 2001).

According to Michael (1994), when motion of the cylinder organizes the wake and cause the shedding frequency to abruptly jump from its nominal value f_{st} to a value equal to the oscillation frequency, f_{ex}, the shedding frequency said to be in locked-in, locked on or synchronized to the cylinder frequency. The first phenomenon reported by Bishop in 1964.

Vortices shed far from the cylinder when cylinder vibration near to its maximum displacement. Zdravkovic (1982) agrees that the vortex is shed from the side opposite the side experiencing maximum displacement when vibration frequency is below the natural shedding frequency and vortex is shed from the same side as the maximum displacement when vibration frequency above the shedding frequency (Blevins, 2001).

Stansby (1979) found that in several key point regarding lock-in phenomenon including shedding behavior at the edges of the lock-in frequency range is similar for uniform and shear flow while the minimum amplitude to ignite lock-in is increase with the increase of Re.

2.3 Flow around Cylinder Structure

When a fluid flow past a bluff body, in this case, a cylindrical structure whose direction is perpendicular to the axis of the bluff- body such as cross-flow ,Cl the bluff-body structure will try to vibrate in a direction normal to the flow direction (Akaydin et.al 2010). This flow induced vibration configuration is controlled by the Reynolds number (Re), could be caused by the turbulence generated by the flow around and in the wake of the cylinder.

When sufficiently large Reynolds number (Re) exceeds a critical value, somehow the cylinder might experience excitations or vibrations, as the unsteady flow around the cylinder separates from a wider section of the body giving rise to periodic vortex shedding from either side of the body, forming pressure differences causing a net force exerted on the bluff-body in the direction perpendicular to the flow and creating vortices in a repeating of swirling vortices known as the von Karman vortex street.

Flow patterns around of bluff bodies under either steady or turbulent ongoing flows have been formed by either 1 shear layer or 2 shear layers on one side or both sides of bodies due to the flow-body interactions depends on characteristics of bluff bodies by means sectional shape and dimension and characteristics of ongoing flow such as steady or unsteady, wind velocity, attack angle and even in-flow movement of body, the around-body flow shear layer can be either stability or instability (Hoa, 2005).

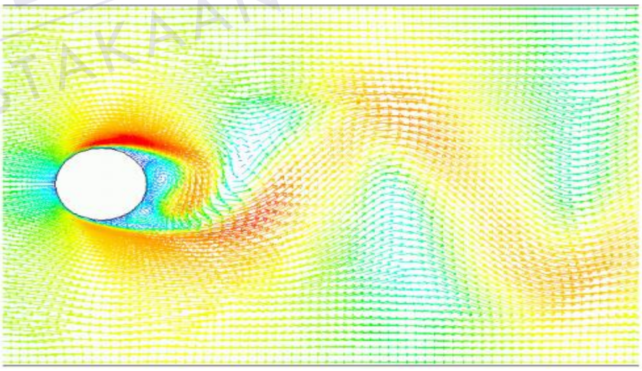


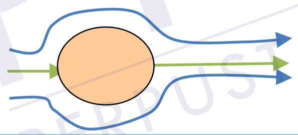
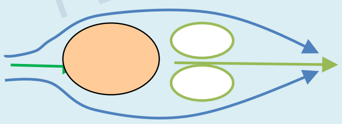
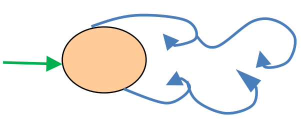
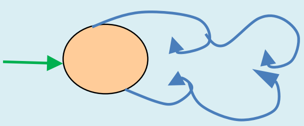
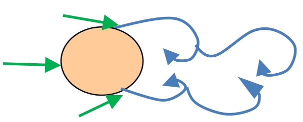
Figure 2.3: Flow around circular cylinder (Gamino, 2013)

2.4 Vortex Shedding

Reynolds (1883) was the first to propose a criterion for differentiation between laminar and turbulent flows in his classic dye visualization and suggested a critical value of for the upper limit of laminar flow. In a second paper in 1895, he showed by time-averaging the Navier-Stokes equations that new extra convection terms appeared in turbulence which have the units of stress and are therefore called Reynolds stresses.

Theodore von Kármán is the person who first stimulated widespread interest and published the first theoretical study of vortex streets in 1911. In 1981 Schatzman, who studied the analysis of a model for the Von Kármán Vortex Street found that the linear stability of the point vortex has been generalized to vortices of finite size and can stabilize the array (Azman, 2008).The vortex shedding around bluff bodies can be classified by some following kinds (Hoa, 2005; Matsumoto 1999):

Table 2.1: Flow regime around smooth, circular cylinder in steady current (Hall-Stinson, 2011; Asyikin, 2012)

	**No separation** **Creeping flow**	**Re < 5**
	A fixed pair of symmetric vortices	5 < Re < 40
	Laminar vortex street	40 < Re <200
	Transition to turbulence in the wake .	200 < Re < 300
	Wake completely turbulent A. Laminar boundary layer separation	300 < Re < 3×10^5 Subcritical

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